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TRACKING SYSTEMS, THEIR MATHEMATICAL MODELS AND THEIR ERRORS

PROGRAM DESCRIPTION

MAY 20, 1964

NASA

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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BY

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INTRODUCTION

In a paper entitled "Tracking Systems, Their Mathematical Models and Their Errors; PART I - THEORY," F. O. Vonbun and W. D. Kahn have presented a theoretical treatment of the RMS-errors associated with the position and velocity of a satellite or spacecraft when tracked by various types of present day tracking systems. The mathematical models of the tracking systems and the method used in solving the error equations given in their paper have been developed by the NASA Systems Analysis Office into an error analysis computer program called ERRAN. A paper "Tracking Systems, Their Mathematical Models and Their Errors; PART II - LEAST SQUARE TREATMENT" by W. D. Kahn and F. O. Vonbun, presently in preparation, will show further development and application of the error models using the method of weighted least squares and will present numerical examples and results based on use of the computer program.

The purpose of the present paper is to show in detail the input and output requirements of the error analysis program ERRAN. One section gives the inputs necessary for running various cases and some sample inputs. Another section gives the various outputs possible along with sample outputs. Finally, the appendix gives the tape units required when running the program. The information given here enables a user of the computer program ERRAN to prepare computer runs in order to make error analysis studies.

This paper represents the beginning for, and will be incorporated in, a program manual to be entitled "Tracking Systems, Their Mathematical Models and Their Errors; PART III - PROGRAM DESCRIPTION" by J. L. Cooley. In the manual a complete description of the application of the equations derived in PART I and PART II will be given along with a description of all features of the computer program.

INPUT

This section contains the following information:

A. Inputs necessary for running a case.

B. Inputs necessary for stacking cases.

C. Sample Input - no options.

D. Sample Input - using options.

A. INPUTS NECESSARY FOR RUNNING A CASE

There are three general blocks to the input. The program requires in succession

1. Orbit information

2. Tracking station information and

3. Case information and options.

The first block (four basic cards and up to nine optional cards) identifies the orbit and provides the necessary information for setting up the orbit, as well as giving any knowledge of the injection errors. The cards in this block are described in the order in which they would be read by the program.

The next block (four basic cards and other optional cards) gives location and tracking information for up to 40 tracking stations. Since there are several variations in the order in which these cards can be read, the different card types in this block will be described first and then the order in which these cards can be read will be given.

Finally, information on the case to be run is given (three required cards and seven optional cards) as well as inputs for various options. The cards in this block are described in the order in which they would be read by the program.

1. ORBIT INFORMATION

CARD 1: Columns 2-72 of card one are reserved for identification of the run. This identification is printed at the top of the output.

CARD 2: This card is a control card used to specify the type of orbit and injection information which follows. The format is (5I3).*

Columns 1-3 specify the type of input on card 4:

+01 = osculating orbital elements (km, degrees)

+02 = inertial position and velocity (km and km/sec)

Columns 4-6 specify whether injection errors are to be input:

+00 = no injection knowledge assumed

+01 = input injection errors for tracking

+02 = input injection errors for tracking and predict these errors to the time given on card 4G.

Columns 7-9 specify the type of input if injection errors are included:

+00 = input the errors in inertial position and velocity at injection (δX_1, δX_2, δX_3, $\delta \dot{X}_1$, $\delta \dot{X}_2$, $\delta \dot{X}_3$) on card 4A - for lack of knowledge of the state at injection assume no correlation between the parameters.

+01 = input the errors in inertial position and velocity at injection on card 4A and input correlations between the parameters on cards 4B-4F.

+02 = input the errors in height, velocity, flight path angle, azimuth, right ascension, and declination (δh, δv, $\delta \gamma$, $\delta \alpha$, $\delta \chi$, $\delta \bar{\delta}$) at injection on card 4A - assume no correlation between the parameters.

+03 = input the errors in height, velocity, flight path angle, azimuth, right ascension, and declination at injection on card 4A and input correlations between the parameters on cards 4B-4F.

* See reference 3 for input/output format types.

Columns 10-12 can be used to change the earth constants:

+00 = retain standard Goddard earth constants built into the program:

M_eG_e (mass of the earth times the Gaussian constant squared) = 398,603.2 km^3/sec^2

f (inverse of flattening) = 298.3

r_e (equatorial radius of earth) = 6378.165 km

-01 = use Siry package constants:

M_eG_e = 398,626.88 km^3/sec^2

f = 297.0

r_e = 6378.388 km

-03 = use international constants:

M_eG_e = 398,626.873 km^3/sec^2

f = 297.0

r_e = 6378.388 km

+01 = input new values for earth constants on card 2B.

Columns 13-15 can be used to change the truncation factor required in solving Kepler's equation:

+00 = retain the figure 10^{-8} radians built into the program

+01 = input a different truncation factor on card 2A.

CARD 2A (OPTIONAL): A new value of the truncation factor used in solving Kepler's equation (in radians) is read in here if so specified on columns 13-15 of card 2. The format is (E8.2).

CARD 2B (OPTIONAL): New values for the earth constants are read in here if so specified on columns 10-12 of card 2. The format is (3E10.5).

Columns 1-10 $M_e G_e$ in km^3/sec^2

Columns 11-20 f

Columns 21-30 r_e in km.

CARD 3: The epoch of the input parameters - the calendar date and universal time - are put on this card. The format is (2(1XI2), 1XI4, 2I3, F7.3).

Columns 2-3 month

Columns 5-6 day

Columns 8-11 year

Columns 13-14 hour

Columns 16-17 minute

Columns 18-24 second (decimal number).

CARD 4: This card contains six orbital elements corresponding to the epoch time in card 3. The format of this card is (6F12.6).

If columns 1-3 of card 2 are +01, then osculating orbital elements are input:

Columns 1-12 semi-major axis of the satellite orbit in km

Columns 13-24 eccentricity of the orbit

Columns 25-36 inclination to the equatorial plane in degrees

Columns 37-48 right ascension of the ascending node in degrees

Columns 49-60 argument of perigee in degrees

Columns 61-72 mean anomaly in degrees.

If columns 1-3 of card 2 are +02, then the inertial position and velocity rectangular coordinates are input:

Columns 1-12, component of position in the X_1-direction (the X_1 axis is directed towards the vernal equinox and lies in the equatorial plane) in km.

Columns 13-24, component of position in the X_2-direction (the X_2 axis lies in the equatorial plane 90 degrees east of the X_1 axis) in km.

Columns 25-36, component of position in the X_3-direction (the X_3 axis is perpendicular to the equatorial plane and is directed north) in km.

Columns 37-48, X_1-component of velocity in km/sec.

Columns 49-60, X_2-component of velocity in km/sec.

Columns 61-72, X_3-component of velocity in km/sec.

CARD 4A (OPTIONAL): If columns 4-6 of card 2 are positive, then injection errors are to be input. Card 4A gives the six diagonal elements of the injection matrix. The format is 6E10.5.

If columns 7-9 of card 2 are +00 or +01, the following input is required:

Columns 1-10, injection error in the X_1-component of position (δX_1) in meters

Columns 11-20, injection error in the X_2-component of position (δX_2) in meters

Columns 21-30, injection error in the X_3-component of position (δX_3) in meters

Columns 31-40, injection error in the X_1-component of position ($\delta \dot{X}_1$) in meters/second

Columns 41-50, injection error in the X_2-component of velocity ($\delta \dot{X}_2$) in meters/second

Columns 51-60, injection error in the X_3-component of velocity ($\delta \dot{X}_3$) in meters/second.

If columns 7-9 of card 2 are +02 or +03, the following input is required:

Columns 1-10, injection error in height above the earth (δh) in meters

Columns 11-20, injection error in the magnitude of the velocity of the spacecraft (δv) in meters/second

Columns 21-30, injection error in flight path angle ($\delta\gamma$) in radians

Columns 31-40, injection error in insertion azimuth ($\delta\alpha$) in radians

Columns 41-50, injection error in the right ascension of the spacecraft at the time of insertion into orbit ($\delta\chi$) in radians

Columns 51-60, injection error in the declination of the spacecraft at the time of insertion into orbit ($\delta\overline{\delta}$) in radians.

CARDS 4B-4F (OPTIONAL): If columns 7-9 of card 2 are +01 or +03, the injection error matrix is non-diagonal. To give the non-diagonal (or correlated) terms, the correlations are read on cards 4B-4F. The format for each card is (5E12.6).

CARD 4B: Columns 1-12, $\rho_{12} = \rho_{21}$

Columns 13-24, $\rho_{13} = \rho_{31}$

Columns 25-36, $\rho_{14} = \rho_{41}$

Columns 37-48, $\rho_{15} = \rho_{51}$

Columns 49-60, $\rho_{16} = \rho_{61}$

CARD 4C: Columns 1-12, $\rho_{23} = \rho_{32}$

Columns 13-24, $\rho_{24} = \rho_{42}$

Columns 25-36, $\rho_{25} = \rho_{52}$

Columns 37-48, $\rho_{26} = \rho_{62}$

CARD 4D: Columns 1-12, $\rho_{34} = \rho_{43}$

Columns 13-24, $\rho_{35} = \rho_{53}$

Columns 25-36, $\rho_{36} = \rho_{63}$

CARD 4E: Columns 1-12, $\rho_{45} = \rho_{54}$

Columns 13-24, $\rho_{46} = \rho_{64}$

CARD 4F: Columns 1-12, $\rho_{56} = \rho_{65}$

CARD 4G (OPTIONAL): If columns 4-6 of card 2 are +02, the injection errors are to be predicted to some time. The prediction time is given on card 4G - this is a time from the epoch time given on card 3. The format is (E20.9).

Columns 1-20, time from epoch (in hours) at which to predict the injection errors.

2. TRACKING STATION INFORMATION

CARD 5: This card is a control card used to specify the type and the order of the tracking station information which follows. Because the order of the cards in this input block is dependent on the options specified in card 5, the various card types will be listed first and then the order of these card types will be given. The format for card 5 is (I3,52A1).

Columns 1-3 give the number of tracking stations available for the run. This number must not be less than 1 nor greater than 40.

Columns 4-55 are used for various options. This portion of card 5 must be blank or contain "D," "E," "S," "C" or combinations of these letters. The letters may be put anywhere in columns 4-55 in any order.

"D" specifies that azimuth rate and elevation rate are to be measured by each tracking station. Then card 7A gives the azimuth rate error and elevation rate error for the tracking stations.

"E" provides for different observational and positional errors at each station. Then there must be separate card 7 (and 7A if specified by "D") input for each station available. Otherwise the observational and positional errors are the same for each tracking station and a single card 7 (and card 7A if so specified by "D") gives the errors.

"S" provides for different station types and sample rates. Then there must be separate card 8 input for each station available. Otherwise the station type and sample rates are the same for each tracking station and are given on a single card 8.

"C" specifies that the angular errors for each tracking station, given on card 7, are direction cosine errors instead of errors in azimuth and elevation.

CARD 6: The station location and station name are given on card 6. There may be up to 40 stations. Each tracking station defined, the total number of which is given in columns 1-3 of card 5, must have a station location card. Since no stations may be added on subsequent cases, all stations to be used for a given run must be input on the first case. The format for card 6 is (3F15.8, 3A6).

Columns 1-15, geodetic latitude of the tracking station (ϕ) in degrees (a decimal)

Columns 16-30, geodetic longitude of the tracking station (λ) in degrees (a decimal)

Columns 31-45, height above geoid of the tracking station (h) in km

Columns 46-63, station name.

CARD 7: The observational and positional errors for a tracking station are given on this card. If columns 4-55 of card 5 do not contain an "E," the errors are the same for each station and only one of these cards is needed. If, however, columns 4-55 of card 5 contain an "E," the errors are different for each station and there must be an error card associated with each station card. The format for card 7 is (7E10.3).

Columns 1-10, standard deviation of the error associated with the range measurement $\sigma_r = \left[E(\delta_r)^2\right]^{1/2}$ in meters.

Columns 11-20, standard deviation of the error associated with the range rate measurement $\sigma_{\dot{r}} = \left[E(\delta_{\dot{r}})^2\right]^{1/2}$ in meters/second.

Columns 21-30, standard deviation of the error associated with the measurements of the azimuthal angle $\sigma_a = \left[E(\delta a)^2\right]^{1/2}$ in radians; or the error in the phase difference in the "1" direction in radians if the direction cosine option "C" is specified on card 5.

Columns 31-40, standard deviation of the error associated with the measurement of the elevation angle $\sigma_\epsilon = \left[E(\delta\epsilon)^2\right]^{1/2}$ in radians; or the error in the phase difference in the "m" direction in radians if the direction cosine option "C" is specified on card 5.

Columns 41-50, standard deviation of the error in the S_1 component of station location (σS_1) in meters.*

Columns 51-60, standard deviation of the error in the S_2 component of station location (σS_2) in meters.*

Columns 61-70, standard deviation of the error in the S_3 component (directed along the local vertical) of station location (σS_3) in meters.*

The program assumes that no perfect measurements are made (i.e., that the standard deviation is not 0 when a measurement is taken).

CARD 7A (OPTIONAL): If option "D" is specified on card 5, then azimuth rate and elevation rate errors are given for each station. In this case card 7A would immediately follow card 7 on any ordering of the tracking station input. The format for card 7A is (2E10.3).

Columns 1-10, standard deviation of the error associated with the measurement of azimuth rate $\sigma_{\dot{a}} = \left[E\left(\delta_{\dot{a}}\right)^2\right]^{1/2}$ in radians/second.

Columns 11-20, standard deviation of the error associated with the measurement of elevation rate $\sigma_{\dot{\epsilon}} = \left[E\left(\sigma_{\dot{\epsilon}}\right)^2\right]^{1/2}$ in radians/second.

CARD 8: The type of tracking station and the sampling rate are given on card 8. The signs of the numbers on this card identify the type of tracking station and the magnitude of the positive quantities gives the sampling rate for an observation. The format of card 8 is (4I10). The sign of the numbers is interpreted as follows:

Columns 1-10	+ range rate is measured
	- range rate is not measured
Columns 11-20	+ range and angles are both measured
	(then columns 21-30 and 31-40 are -)
	- range and angles are not both measured

* See appendix A of reference 1 for the derivation of S_1-S_2-S_3 coordinates.

Columns 21-30 + range is measured but not angles

- range is not measured

Columns 31-40 + angles are measured (either azimuth and elevation or direction cosines depending upon whether option "C" is specified; also angular rates are measured if option "D" is specified) but not range.

- angles are not measured

Then the possible types of tracking stations are:

+ - - -	range rate station
+ + - -	range, range rate, angles station
+ - + -	range and range rate station
+ - - +	range rate and angles station
- + - -	range and angles station
- - + -	range station
- - - +	angles station

In addition angular rates may be measured by using option "D." Azimuth and elevation, and the direction cosine, measurements may in effect be made separately by setting the standard deviation of the error associated with one of the angular measurements very large. Note that errors in direction cosine rates are not considered in this program.

The magnitude of the positive numbers is interpreted as follows:

Columns 1-10 give a multiple of the basic time increment (Δt, given on card 10) in which to make a range rate measurement.

Columns 11-20 give a multiple of the basic time increment in which to make range and angle (and angular rate) measurements together.

Columns 21-30 give a multiple of the basic time increment in which to make a range measurement.

Columns 31-40 give a multiple of the basic time increment in which to make angle (and angular rate) measurements.

Thus the sampling rates for various measurements may be different. This allows for independent components at the same tracking site. Should the sampling rates be the same for all measurements, the sampling rate in most cases would coincide with the basic time interval Δt (and in this case the integers on card 8 would be +1 or -1).

If columns 4-55 of card 5 do not contain an "S", the station type and sampling rate are the same for each station; and only one of these cards is needed. If, however, columns 4-55 contain an "S", the station types and/or sampling rates are different for each station; and there must be a sampling card associated with each station card.

Following card 5, cards 6-8 may be combined in several ways depending on the options used on card 5. Whenever option "D" is specified, a card 7A follows any card 7, wherever card 7 appears. A complete list of the various tracking station input possibilities for cards 6-8 follows:

I. <u>NO "E" OR "S" ON CARD 5</u>

CARD 7: Errors are the same for each station

CARD 7A (OPTIONAL): If option "D" is used

CARD 8: Same station type and sample rates

CARD 6: Station location and name for station 1

CARD 6:} repeat card 6 for each station to be defined

II. <u>CARD 5 CONTAINS "E" BUT NOT "S"</u>

CARD 8: Same station type and sample rates

CARD 6: Station location and name for station 1

CARD 7: Errors for station 1

CARD 7A (OPTIONAL): If option "D" is used

CARD 6:

CARD 7: repeat cards 6, 7 (and 7A) for each station to be defined.

CARD 7A (OPTIONAL):

III. CARD 5 CONTAINS "S" BUT NOT "E"

CARD 7: same errors for each station

CARD 7A (OPTIONAL): If option "D" is used

CARD 6: Station location and name for station 1

CARD 8: Station type and sample rates for station 1

CARD 6:
CARD 8: repeat cards 6 and 8 for each station to be defined

IV. CARD 5 CONTAINS BOTH "S" AND "E"

CARD 6: Station location and name for station 1

CARD 7: Errors for station 1

CARD 7A (OPTIONAL): If option "D" is used

CARD 8: Station type and sample rates for station 1

CARD 6:

CARD 7: repeat cards 6, 7 (and 7A), and 8 for each station to be defined

CARD 7A (OPTIONAL):

CARD 8:

Information must be given for the number of stations specified in columns 1-3 of card 5.

3. CASE INFORMATION AND OPTIONS

CARD 9: The first card in this block gives the observational interval and a case description letter code. The case description letter code in general controls the time and type of printouts, and allows for the changing of various built-in constants. The format for card 9 is (2F10.5, 52A1).

Columns 1-10 give the starting time (t_o) for the observational period. This time (universal time) is given in hours (a decimal) referenced to the epoch specified in card 3; that is, $t_o = 0$ is equivalent to the given epoch time.

Columns 11-20 give the terminating time (t_{max}) for the observational period. This time is given in hours from epoch (a decimal) and must be greater than the starting time t_o.

Columns 21-72 are used to specify case options. These 52 columns must be blank or contain the letters "P, F, G, Z, X, V, L, A, B, M, or S" or any combination of these letters. The letters may be placed anywhere in columns 21-72 in any order. The first 7 letters above require input information which is given on cards 11B-11G in the stated order.

CARD 10: This card gives the basic time increment (Δt) which in many cases will be the sampling rate. The observations and the printouts occur at multiples of this time increment Δt (see cards 8 and 11B). The format for card 10 is (E20.9).

Columns 1-20, time increment (Δt) in seconds.

CARD 11: This card (and possibly card 11A) tells which of the available stations are actually to be used in the tracking network for the present case. The numbers for the stations to be used are given successively in three column fields, the numbers themselves being determined by the order in which the stations were originally input. The format for card 11 (and 11A) is (20I3).

Columns 1-3 give the number of the 1st station to be used.

Columns 4-6 give the number of the 2nd station to be used.

. . .

Columns 58-60 give the number of the 20th station to be used. A blank or a zero number in a three-column field terminates the read. If 20 or more tracking stations are to be used, a second card (11A) is required. If exactly 20 stations are to be used, card 11A will be blank in order to terminate the read.

CARD 11A (OPTIONAL): If more than 20 tracking stations are to be used, the numbers are continued in three-column fields, as on card 11, up to a maximum of 40 stations. A blank or a zero number in a three-column field terminates the read.

Columns 1-3 give the number of the 21st station to be used.

Columns 4-6 give the number of the 22nd station to be used.

. . .

Columns 58-60 give the number of the 40th station to be used.

CARD 11B (OPTIONAL): This card is used only if option "P" is specified on card 9. Option "P" allows the printing of local lines on a supplementary output tape. Local lines information includes the distance of the satellite from the center of the earth and the velocity of the satellite; the range, azimuth, elevation, range rate, azimuth rate, and elevation rate with respect to each tracking station currently observing the satellite; and the eccentric anomaly of the orbit. Card 11B gives the multiple of the basic time increment Δt at which to print the local lines. The format for card 11B is (I10).

Columns 1-10, multiple of Δt (Δt is given on card 10) at which to print the local lines.

CARD 11C (OPTIONAL): This card is used only if option "F" or "G" is specified on card 9. Option "F" provides for printing out the variance-covariance matrices of the errors in position and velocity and in the orbital elements at specified time lapses. The number of time points to consider must be input. As soon as observations have been made at the specified number of time points, the cumulated errors (i.e., the errors from the starting time t_o) are printed out. Option "G" provides for both the cumulated and the interim errors (i.e., the errors generated in the interval since the last timewise printout) to be printed out at the specified time lapses. The format for card 11C is (I10).

Columns 1-10, number of observation points to process before printing out the cumulated (and interim) errors.

CARD 11D (OPTIONAL): This card is used only if option "Z" is specified on card 9. The program has built-in visibility bounds of 5° to 90°. These visibility bounds may be changed by using option "Z". The format of card 11D is (2E20.9).

Columns 1-20, visibility bound on the horizon in degrees.

Columns 21-40, visibility bound on the zenith in degrees.

CARD 11E (OPTIONAL): This card is used only if option "X" is specified on card 9. Option "X" is used when it is desired to predict the variance covariance matrix of the errors in position and velocity (and in h, v, γ, α, χ, $\bar{\delta}$ - see option "M") to some specified time. By using this option, an additional variance covariance matrix is obtained since the errors are automatically evaluated at the time of the last observation. The prediction time is given on this card. The format of card 11E is (E20.9).

Columns 1-20, time in hours, from the epoch given in card 3, at which to evaluate the variance covariance matrix of errors.

CARD 11F (OPTIONAL): This card is used only if option "V" is specified on card 9. In the program the uncertainty factor in the velocity of light ($\Delta c/c$) is defined as 1.0×10^{-6}. This factor may be changed by using option "V". The format of card 11F is (E20.9).

Columns 1-20, velocity of light error factor.

CARD 11G (OPTIONAL): This card is used only if option "L" is specified on card 9. The program uses a value of 2.795 for the scaling coefficient B^2 in the ellipsoid of errors; this corresponds to an error ellipsoid having a 95 percent probability that the error is contained within its bounds (See Figure 1). The coefficient B^2 may be changed by using option "L". The format of card 11G is (E20.9).

Columns 1-20, ellipsoid of errors scaling coefficient.

There are four options not requiring additional input information. These are options "A", "B", "M", and "S".

If option "A" is specified on card 9, the variance covariance matrices of cumulated errors are printed out at the end of a pass (i.e., when one of the observing stations can no longer view the satellite).

If option "B" is specified on card 9, the variance covariance matrices of both the cumulated and interim (i.e., the errors generated since the end of the previous pass) errors are printed out at the end of a pass.

If option "M" is specified on card 9, the variance covariance matrix of the errors in h, v, γ, α, χ, and $\overline{\delta}$ is printed whenever the errors in position and velocity are printed.

If option "S" is specified on card 9, no observations are taken at a time point unless all observing stations can view the vehicle. This gives simultaneous observations. Otherwise the stations observe independently.

This completes the information required to run a case.

B. INPUTS NECESSARY FOR STACKING CASES

This program allows for many cases to be processed on the same run. It is in general not necessary to repeat that part of the input which remains unchanged from case to case. Thus, parametric studies may be made by giving new input information for only those parameters being changed. The options given on the first card of any new case, card 12, control the input for the case. Each case follows immediately after the preceding one. The cards are described in the order in which they would be read by the program.

CARD 12: Each additional case starts with this card, which is similar to card 9. This card gives the observational interval and a case description letter code. If the observational interval is not given (i.e., t_o and t_{max} are both 0), then the observational interval used on the previous case is retained. The case description letter code is expanded on cases after the first, and the order in which options occur on this card now affects some of the options. The code is processed consecutively from column 21 through column 72. The format for card 12 is (2F10.5, 52A1).

Columns 1-10 give a (possible) new starting time (t_o) for the observational period, in hours (a decimal) from the epoch specified in card 3.

Columns 11-20 give a (possible) new terminating time t_{max} for the observational period, in hours (a decimal) from epoch. This time must be greater than the starting time t_o. However, if t_o and t_{max} are both 0 (or columns 1-20 are blank), then the same t_o and t_{max} used on the previous case are retained.

Columns 21-72 are used to specify case options and changes from the previous case. These 52 columns must be blank or contain the letters "O, T, N, P, F, G, H, J, I, Z, X, Y, V, L, E, R, A, B, C, D, M, S, or K" or any combination of these letters. The letters may be placed anywhere in columns 21-72. However, the order in which these letters are processed (from columns 21 to 72) affects some of the options. Input information for those options requiring such is given on cards 12A-12P in the given order.

CARDS 12A-12D (OPTIONAL): These cards are required only if option "O" is specified on card 12; option "O" is used to change orbit and/or injection information. If option "O" is not specified, the orbit (and injection information) used on the previous case is retained. However, if option "O" is specified, an orbit block, consisting of cards having the same information and format as cards 1-4 (and any of the optional cards 4A-4G that are required by the control card), is read. Note that the same injection information, or lack of such, automatically carries over to the next case unless option "O" is specified.

CARD 12E (OPTIONAL): This card is required only if option "T" is specified on card 12; option "T" is used to change the basic time increment (or sampling rate) Δt. If option "T" is not used, the time increment Δt is retained from the previous case. However, if option "T" is specified, one card is read having the same information and format as card 10.

CARD 12F (OPTIONAL): This card is required only if option "N" is specified on card 12; option "N" is used to change the stations in the tracking network for the current case. If option "N" is not used, the tracking stations are the same as those of the previous case. However, if option "N" is specified, a card having the same information and format as card 11 is read. Also if 20 or more tracking stations are to be used, an additional card having the same information and format as card 11A is read.

CARD 12G (OPTIONAL): This card is required only if option "P" is specified on card 12; as in the first case, option "P" provides for the printing of local lines on a supplementary output tape. Since option "P" is not retained from case to case, the local lines are printed for a case only if option "P" is specified on that case. If option "P" is specified, the multiple of the basic time increment Δt in which to print must be given on a card with the same information and format as card 11B.

CARD 12H (OPTIONAL): This card is required in certain (but not all) instances where options "F" or "G" are specified on card 12. The options "F", "G", "H", "J", and "I" all refer to the timewise printout of the variance covariance matrices of the errors. The meaning of these options is as follows:

OPTION "F", print the cumulated errors at specified time lapses.

OPTION "G", print both the interim errors and the cumulated errors at specified time lapses.

OPTION "H", cancel options "F" or "G", and also discard the time multiple for printing

OPTION "J", cancel options "F" or "G", but retain the time multiple for printing for possible use on later cases.

OPTION "I", cancel the printout of the interim errors only, retaining the printout of the cumulated errors (i.e., cancel "G" but retain "F").

Since options "H", "J", and "I" cancel previously specified, the order that these options appear on card 12 is significant. Card 12 is processed from columns 21-72. Options "I" and "J" retain the time multiple for printing; thus the number of observation points to process before printing the cumulated (and interim) errors is read the first time one of options "F" or "G" appear on a run, and thereafter only when option "H" has preceded options "F" or "G". Options "F" and "G" are retained from case to case until cancelled by "H", "J", or "I". When the time multiple for printing is required input, one card is read with the same information and format as card 11C.

CARD 12I (OPTIONAL): This card is required only if option "Z" is specified on card 12; option "Z" allows the visibility bounds for tracking to be changed. If option "Z" is not used, the horizon and zenith limits are retained from the previous case. However, if option "Z" is specified, a card having the same information and format as card 11D is read.

CARD 12J (OPTIONAL): This card is required only if option "X" is specified on card 12. Option "X" is used to generate an additional variance covariance matrix of the errors in position and velocity (and in h, v, γ, α, χ, $\overline{\delta}$ - see option "M"). Options "X" and "Y" are related:

OPTION "X", print the variance covariance matrix at the given time

OPTION "Y", cancel "X".

If neither "X" nor "Y" is present on card 12, no additional input is needed. The same situation (either no print or a print at the same time) as on the previous case will prevail. Thus option "X" is retained until cancelled by "Y". The prediction time is retained until option "X" again appears. Then (assuming "Y" does not follow "X" on card 12), one card having the same information and format as card 11E is read.

CARD 12K (OPTIONAL): This card is required only if option "V" is specified on card 12; option "V" is used to change the uncertainty factor in the velocity of light. If option "V" is not used, the uncertainty factor is retained from the previous case. However, if option "V" is specified, a card having the same information and format as card 11F is read.

CARD 12L (OPTIONAL): This card is required only if option "L" is specified on card 12; option "L" is used to change the scaling coefficient for the ellipsoid of errors (See Figure 1). If option "L" is not used, the scaling factor is retained from the previous case. However, if option "L" is specified, a card having the same information and format as card 11G is read.

CARDS 12M-12P: These cards are used only if options "E" and/or "R" are specified on card 12. These options change the tracking station information:

OPTION "E", read new observational and positional errors for the tracking stations

OPTION "R", read new station types and sample rates for the tracking stations.

If one or both of these options are chosen, the loop which reads the tracking station information (cards 5-8 for the first case) is entered. The first card read (card 12M) is always a card with the same format as card 5. However, now the number in columns 1-3 gives the number of stations for which new information is to be entered (not necessarily the same number as the total number of stations available); the stations, starting with station 1, are processed successively and thus those stations requiring additional input information during a run should be put ahead of those stations not requring any additional input information so that less input cards will be needed in certain instances. The same options are available on card 12M as on card 5; however, the option "E" on card 12M is applicable only if option "E" is specified on card 12, option "S" on card 12M is applicable only if option "R" is specified on card 12, and options "D" and "C" are not retained unless they are specified on card 12M.

The order of the tracking station input is the same as on the first case except that no cards are read for the tracking station information not being changed. Thus, there are never any station location cards similar to card 6 read after the first case. Cards of type 7 (and 7A if "D" is specified on card 12M) are read only if option "E" is specified on card 12; that is, only if the station errors are to be changed. Cards of type 8 are read only if option "R" is specified on card 12; that is, only if the station type and sample rates are to be changed.

Thus, the tracking station information is changed on cases beyond the first by reading a control card similar to card 5 and then reading station error cards and/or station type and sample rate cards in the order specified by the control card. This ordering is given after the description of card 8.

There are 7 options not requiring additional input information. These are options "A", "B", "C", "D", "M", "S", and "K".

Options "A", "B", "C", and "D" all refer to the passwise printout of the variance covariance matrices of the errors. The meaning of these options is as follows:

OPTION "A", print the cumulated errors at the end of a pass (whenever one of the observing stations can no longer view the satellite).

OPTION "B", print both the interim errors and the cumulated errors at the end of a pass

OPTION "C", cancel options "A" and "B"

OPTION "D", cancel the printout of the interim errors only, retaining the printout of the cumulated errors (i.e., cancel "B" but retain "A").

Since options "C" and "D" cancel options previously specified, the order that these options appear on card 12 is significant. Options "A" and "B" are retained from case to case until cancelled by "C" or "D".

Option "M" is used to print the variance covariance matrix of the errors in h, v, γ, α, χ, and $\bar{\delta}$ whenever the errors in position and velocity are printed. This option is reversible; "M" means print the first time "M" is used, do not print the second time "M" is used, etc. Once specified, the option carries over from case to case until "M" is again specified on card 12.

Option "S" is used to force all of the observing stations to view simultaneously; no observations are taken at a time point unless all observing stations can view the vehicle. Option "S" is not retained from case to case. Thus, the stations observe independently unless option "S" is specified on card 12.

Option "K" is used to continue with the same case as the previous one. If "K" is not used the variance covariance matrices are returned to their original form at injection. However, if "K" is specified, these matrices are kept in the same form as they were at the termination of the previous case. This allows a case to be continued after certain parameters have been changed. For instance, the interval for a timewise printout could be changed when a different phase of a lunar orbit was entered. This is also useful when the beginning time t_o is varied though the same terminating time t_{max} is used. Option "K" is not retained from case to case.

Cards 12A-12P should appear in the given order regardless of the order of the options on card 12. Any number of cases may be stacked on the same run--this may be done by repeating cards 12-12P for each new case.

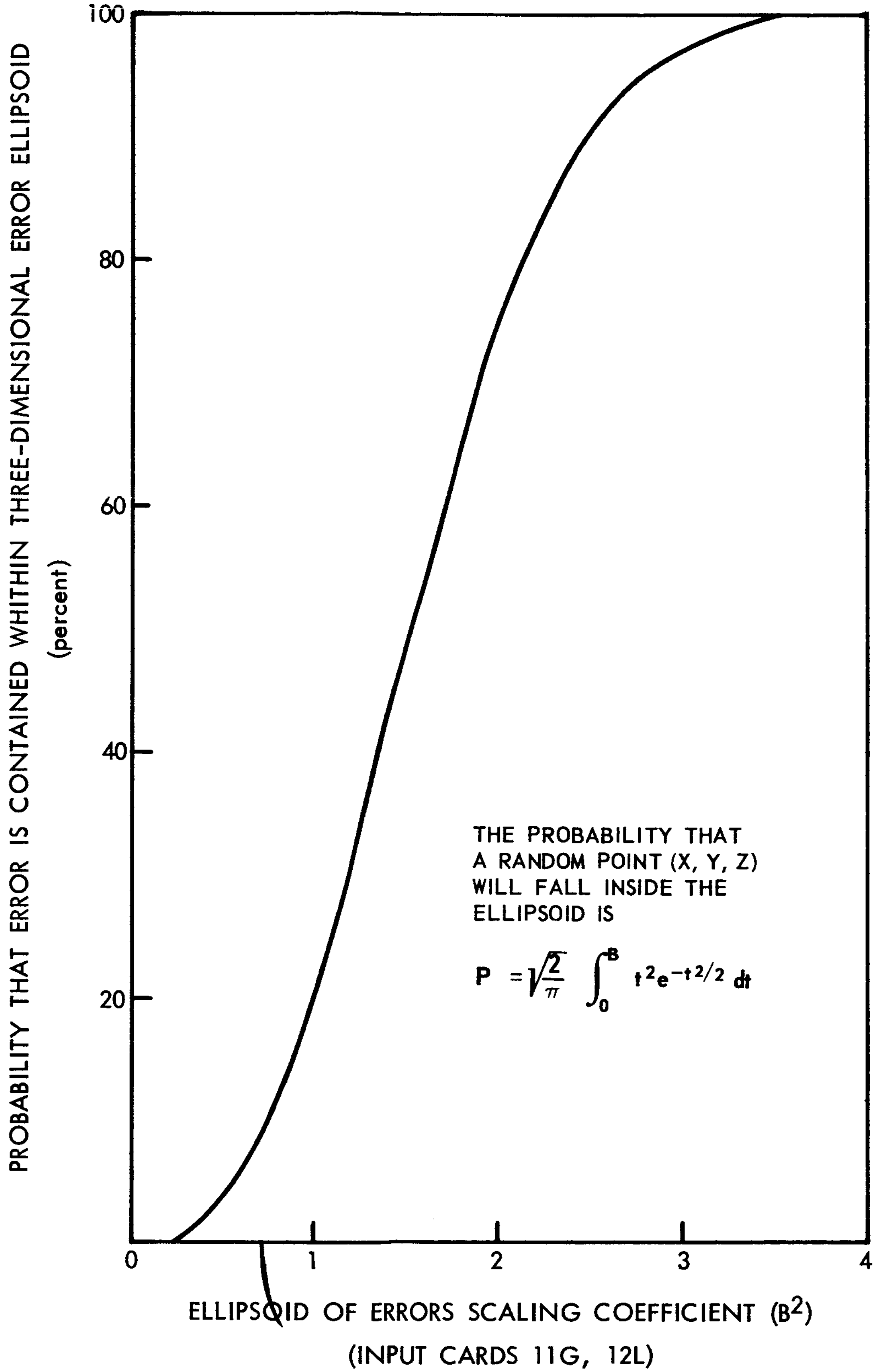
It is suggested that 3 cards be put at the end of a run to allow an exit at the termination of the run. A card similar to card 12 should contain option "O" only. The next card could contain any identification (such as "END OF RUN") in columns 2-72. Finally, a blank card sends the program to the EXIT routine.

C. SAMPLE INPUT - NO OPTIONS

Cards 1-11 are always required for the first case of any run. In addition, other optional cards may be used. A sample case will be given here where cards 1-11 are the only cards required for a run.

Assume a certain parking orbit at a height of 200 kilometers above the earth having the following characteristics:

Epoch	= August 5, 1961; $0^h05^m0.6^s$
Semi-major axis	= 6625.6 km
Eccentricity	= .00712
Inclination	= 28.5°
Right Ascension of Ascending Node	= 143.984°


PROBABILITY THAT ERROR IS CONTAINED WHITHIN THREE-DIMENSIONAL ERROR ELLIPSOID
(percent)
100
80
60
40
20
0
1
2
3
4
THE PROBABILITY THAT A RANDOM POINT (X, Y, Z) WILL FALL INSIDE THE ELLIPSOID IS
$P = \sqrt{\frac{2}{\pi}} \int_0^B t^2 e^{-t^2/2}\, dt$
ELLIPSOID OF ERRORS SCALING COEFFICIENT (B^2)
(INPUT CARDS 11G, 12L)

Argument of Perigee = 97.0°

Mean Anomaly at Epoch = 0.0

Use a tracker located at Carnarvon, Australia:

Latitude = -24.86667° (south latitude)

Longitude = 113.63333

Height = 0.0 meters

Assume that there are no station location errors. Also assume that this tracker measures range, range rate, and angles with the following accuracies:

Range δr = ±15 meters

Range Rate $\delta \dot{r}$ = ±0.1 meters/sec

Azimuth $\delta \alpha$ = $\pm 2 \times 10^{-4}$ radians

Elevation $\delta \epsilon$ = $\pm 2 \times 10^{-4}$ radians

Then, taking a sampling rate or tracking schedule of one measurement every second (i.e., use $\Delta t = 1$ second), the error in position and velocity at the end of the first pass over Carnarvon may be evaluated. It is recommended that a station prediction program be used beforehand to calculate the observation time. Although this could be done with this program, using option "P", a program designed especially for this purpose would be more efficient. Assume that Carnarvon views the vehicle in an interval between 45 minutes after epoch to 54 minutes after epoch.

The first four data cards give the orbit information; the next four cards give the tracking station information; and the next three cards give the case information. The last three cards are only used to exit from the program at the conclusion of the run.

The data setup is as follows:

```
 ERRØR ANALYSIS - PARKING ØRBIT - LAUNCH AZIMUTH 90 , HEIGHT 200 KM.         CARD 1
+01                                                                           CARD 2
 08/05/1961 00 05 00.600                                                      CARD 3
 6625.6     0.00712     28.5        143.984       97.0      0.0               CARD 4
  1                                                                           CARD 5
    15.0E0     0.1E0     2.0E-4     2.0E-4     0.0E0     0.0E0     0.0E0      CARD 7
        +1         +1         -1         -1                                   CARD 8
-24.86667      113.63333     0.0             CARNARVON                        CARD 6
       .75        .90                                                         CARD 9
               1.0E0                                                          CARD 10
  1                                                                           CARD 11
                             Ø                                                END 1
END END END END END END END END END END END END END END END END END END       END 2
                                                         (BLANK CARD)         END 3
```

D. SAMPLE INPUT - USING OPTIONS

In addition to the required cards, several optional cards will now be used. Also several cases will be stacked for the same run.

Assume a 200 kilometer parking orbit having the following characteristics:

Epoch	= August 5, 1961; $0^h05^m0.6^s$
Position in X_1 - direction	= -2725.62662 km
Position in X_2 - direction	= -5112.72467 km
Position in X_3 - direction	= 3115.55615 km
Velocity in X_1 - direction	= 6.76344121 km/sec
Velocity in X_2 - direction	= -3.88244987 km/sec
Velocity in X_3 - direction	= 0.45426302 km/sec

For this case assume injection errors in position and velocity at epoch (without correlation) as follows:

$$|\delta X_1| = 200 \text{ meters}$$

$$|\delta X_2| = 200 \text{ meters}$$

$$|\delta X_3| = 200 \text{ meters}$$

$$|\delta \dot{X}_1| = 50 \text{ meters/sec}$$

$$|\delta \dot{X}_2| = 50 \text{ meters /sec}$$

$$|\delta \dot{X}_3| = 50 \text{ meters/sec}$$

Before tracking, these injection errors will be predicted to 90 minutes after epoch. This time is given on card 4G.

Consider trackers located at Carnarvon and at Guaymas as follows:

	Carnarvon	Guaymas
Latitude	= -24.86667° (south)	= 28.03333° (north)

Longitude	= 113.63333° (east)	= -110.83° (west)
Height	= 0.0	= 0.0

Assume no station location errors.

Let each station measure range, range rate, and angles but have different accuracies as given below:

	Carnarvon	Guaymas
Range	δr = ±15 meters	δr = ±6 meters
Range Rate	$\delta \dot{r}$ = ±0.1 meters/sec	$\delta \dot{r}$ = ±0.1 meters/sec
Azimuth	$\delta \alpha$ = ±2 x 10^{-4} radians	$\delta \alpha$ = ±6 x 10^{-4} radians
Elevation	$\delta \epsilon$ = ±2 x 10^{-4} radians	$\delta \epsilon$ = ±6 x 10^{-4} radians

From a station prediction routine, it is found that Carnarvon views the vehicle in an interval between 45 minutes after epoch to 54 minutes after epoch, and Guaymas views the vehicle in an interval between 82 minutes after epoch and 90 minutes after epoch. Then, taking a measurement every second, the error in position and velocity may be evaluated at every 60 observation points by using option "F". Also the error may be evaluated at the end of the passes over Carnarvon and Guaymas by using option "B". The interim feature of option "B" also gives the errors for the Guaymas measurements alone. For this first case, both stations will track the vehicle, so the station predictions will be generated every 15 seconds by using option "P".

The first 6 data cards give the orbit information, the next 6 cards give the tracking station information, and the next five cards give the case information.

For case 2, retain the same orbit and tracking stations. However, now consider range and angle tracking only. Thus option "R" must be used to change the station type. In addition the timewise printout can be discontinued by using option "H". Option "P" is automatically discontinued, and option "B" is automatically retained. Note that the same starting and ending times are retained by leaving columns 1-20 of card 12 blank. The errors need not be changed since the range rate variance will automatically be neglected for range and angle tracking. Cards 18-20 of the run give the information for case 2.

For case 3, restricting the time interval to be 45 minutes to 54 minutes gives tracking from Carnarvon only. Thus the station number need not be changed even though only one station, not 2, will track the vehicle. The sampling rate may be changed to six seconds by using option "T". In addition, the error at the end of the pass over Carnarvon may be predicted to the start of the pass over Guaymas by using option "X" and giving the prediction time, say 1 hour 23 minutes from epoch. Cards 21-23 of the run give the information for case 3.

Cards 24-26 are used only to exit from the program at the conclusion of the run.

By appropriate choice of options in the program, many types of parametric studies may be made.

```
ERRØR ANALYSIS - PARKING ØRBIT A90 H200 , 2 STATIØNS                              CARD 1
+02+02                                                                            CARD 2
08/05/1961 00 05 00.600                                                           CARD 3
-2725.62662 -5112.72467 3115.55615  6.76344121  -3.88244987 0.45426302            CARD 4
    200.0       200.0       200.0       50.0       50.0       50.0                CARD 4A
                1.5E0                                                             CARD 4G
  2             E                                                                 CARD 5
         +1          +1          -1          -1                                   CARD 8
-24.86667       113.63333       0.0                CARNARVØN                      CARD 6
    15.0E0      0.1E0      2.0E-4      2.0E-4      0.0E0      0.0E0      0.0E0    CARD 7
 28.03333       -110.83         0.0                GUAYMAS                        CARD 6
     6.0E0      0.1E0      6.0E-4      6.0E-4      0.0E0      0.0E0      0.0E0    CARD 7
       .75        1.5           P  F  B                                           CARD 9
                1.0E0                                                             CARD 10
  1  2                                                                            CARD 11
        15                                                                        CARD 11B
        60                                                                        CARD 11C
                                H  R                                              CARD 12
  2                                                                               CARD 12K
        -1           +1          -1          -1                                   CARD 12L
       .75          .90         T  X                                              CARD 12
                6.0E0                                                             CARD 12E
            1.38333E0                                                             CARD 12I
                                Ø                                                 END 1
 END OF RUN                                                                       END 2
                                                   (BLANK CARD)                   END 3
```

OUTPUT

This section contains the following information:

A. Program output on the main tape.

B. Program output on the supplementary tape.

C. Sample output on the main tape.

D. Sample output on the supplementary tape.

A. PROGRAM OUTPUT ON THE MAIN TAPE

The main tape is designated as logical tape 3. The output on this tape consists of the orbit information; injection error variance covariance matrices and ellipsoids of errors if injection errors are assumed; tracking station information for the number of stations observing on the case; and finally, variance covariance matrices of the errors in the orbital elements and in position and velocity, as well as the ellipsoid of errors, resulting from the options specified for the case.

1. ORBIT INFORMATION - PAGE 1

TRACKING SYSTEM ERROR ANALYSIS

(1.1)

(1.2)	TOLERANCE REQUIRED FOR XKEPZ FUNCTION
(1.3)	EQUATORIAL RADIUS OF EARTH IN KM.
(1.4)	INVERSE OF FLATTENING
(1.5)	GM (KM. CUBED/SECONDS SQUARED)
(1.6)	EPOCH DATE OF PARAMETERS
(1.7)	EPOCH TIME OF PARAMETERS - UT2
(1.8)	INPUT OPTION NUMBER
	INPUT PARAMETERS ARE- - -

ORBITAL ELEMENTS - OSCULATING

REQUIRED UNITS - ALL ANGLES IN DEGREES, SEMI-MAJOR AXIS IN KILOMETERS

(1.9a)	SEMI-MAJOR AXIS - KILOMETERS
(1.10a)	ECCENTRICITY
(1.11a)	INCLINATION - DEGREES
(1.12a)	R.A.ASC. NODE - DEGREES
(1.13a)	ARG. OF PERIGEE - DEGREES
(1.14a)	MEAN ANOMALY - DEGREES

GEOCENTRIC EQUATORIAL INERTIAL COORDINATES

REQUIRED UNITS - KILOMETERS AND KILOMETERS/SECOND

(1.9b)	X1 - KILOMETERS
(1.10b)	X2 - KILOMETERS
(1.11b)	X3 - KILOMETERS
(1.12b)	VX1 - KM/SEC
(1.13b)	VX2 - KM/SEC
(1.14b)	VX3 - KM/SEC

(1.1) Identification of the run from input card 1.

(1.2) Truncation factor used in solving Kepler's equation—either the built-in value of 10^{-8} radians or the value from input card 2A.

(1.3) Equatorial radius of the earth—one of the built-in value of 6378.165 km. or 6378.388 km., or the value from input card 2B.

(1.4) The inverse of flattening—one of the built-in values of 297.0 or 298.3, or the value from input card 2B.

(1.5) The mass of the earth times the Gaussian constant squared—one of the built-in values of 398,603.2 km^3/sec^2, 398,626,873 km^3/sec^2, or 398,626.88 km^3/sec^2, or the value from input card 2B.

(1.6) The epoch date of the parameters—month, day, and year from input card 3.

(1.7) The epoch time of the parameters—hour, minute and second from input card 3.

(1.8) The input option number—from columns 1-3 of input card 2.

For input option number 1:

(1.9a) Semi-major axis of the satellite orbit in kilometers—from input card 4.

(1.10a) Eccentricity of the orbit—from input card 4.

(1.11a) Inclination of the orbit to the equatorial plane in degrees—from input card 4.

(1.12a) Right ascension of the ascending node in degrees—from input card 4.

(1.13a) Argument of perigee in degrees—from input card 4.

(1.14a) Mean anomaly at epoch in degrees—from input card 4.

For input option number 2:

(1.9b) Component of position in the X_1-direction in kilometers—from input card 4.

(1.10b) Component of position in the X_2-direction in kilometers—from input card 4.

(1.11b) Component of position in the X_3-direction in kilometers—from input card 4.

(1.12b) Component of velocity in the X_1-direction in kilometers/second—from input card 4.

(1.13b) Component of velocity in the X_2-direction in kilometers/second—from input card 4.

(1.14b) Component of velocity in the X_3-direction in kilometers/second—from input card 4.

2. ORBIT INFORMATION - PAGE 2

(2.1)

QUANTITIES COMPUTED FROM INPUT

(2.2)	EPOCH DATE OF PARAMETERS
(2.3)	EPOCH TIME OF PARAMETERS - UT2

POSITION AND VELOCITY VECTORS - GEOCENTRIC EQUATORIAL INERTIAL

(2.4)	X1 - KILOMETERS
(2.5)	X2 - KILOMETERS
(2.6)	X3 - KILOMETERS
(2.7)	VX1 - KM/SEC
(2.8)	VX2 - KM/SEC
(2.9)	VX3 - KM/SEC
(2.10)	R - KILOMETERS
(2.11)	V - KM/SEC

ORBITAL ELEMENTS

OSCULATING ELEMENTS

(2.12)	SEMI-MAJOR AXIS - KILOMETERS
(2.13)	ECCENTRICITY
(2.14)	INCLINATION - DEGREES
(2.15)	R.A.ASC. NODE - DEGREES
(2.16)	ARG. OF PERIGEE - DEGREES
(2.17)	MEAN ANOMALY - DEGREES
(2.18)	PERIOD - HOURS
(2.19)	- MINUTES
(2.20)	MEAN MOTION - DEGREES/HOUR
(2.21)	SIDEREAL TIME AT EPOCH - DEGREES
(2.22)	PERICENTER - KILOMETERS
(2.23)	APOCENTER - KILOMETERS

(2.1) Identification of the run from input card 1.

(2.2) The epoch date of the parameters—month, day, and year from input card 3.

(2.3) The epoch time of the parameters—hour, minute and second from input card 3.

(2.4) Component of position in the X_1-direction in kilometers—from input card 4 or computed from the orbital elements.

(2.5) Component of position in the X_2-direction in kilometers—from input card 4 or computed from the orbital elements.

(2.6) Component of position in the X_3-direction in kilometers—from input card 4 or computed from the orbital elements.

(2.7) Component of velocity in the X_1-direction in km/sec—from input card 4 or computed from the orbital elements.

(2.8) Component of velocity in the X_2-direction in km/sec—from input card 4 or computed from the orbital elements.

(2.9) Component of velocity in the X_3-direction in km/sec—from input card 4 or computed from the orbital elements.

(2.10) Magnitude of the geocentric equatorial inertial position vector in kilometers.

(2.11) Magnitude of the geocentric equatorial inertial velocity vector in km/sec.

(2.12) Semi-major axis of the satellite orbit in kilometers—from input card 4 or computed from the position and velocity vectors.

(2.13) Eccentricity of the orbit—from input card 4 or computed from the position and velocity vectors.

(2.14) Inclination of the orbit to the equatorial plane from input card 4 or computed from the position and velocity vectors.

(2.15) Right ascension of the ascending node in degrees—from input card 4 or computed from the position and velocity vectors.

(2.16) Argument of perigee in degrees—from input card 4 or computed from the position and velocity vectors.

(2.17) Mean anomaly at epoch in degrees—from input card 4 or computed from the position and velocity vectors.

(2.18) Period of the satellite orbit in hours.

(2.19) Period of the satellite orbit in minutes.

(2.20) Mean motion of the satellite along the orbit in degrees/hour.

(2.21) Greenwich sidereal time at epoch in degrees.

(2.22) Pericenter of the orbit ($a(1-e)$) in kilometers.

(2.23) Apocenter of the orbit ($a(1+e)$) in kilometers.

3. INJECTION ERROR VARIANCE - COVARIANCE MATRICES

VARIANCE - COVARIANCE MATRIX OF ERRORS AT INJECTION

	X1	X2	X3	X1.	X2.	X3.	
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	(3.1)	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
	*	*	*	*	*	*	
	(3.2)	(3.2)	(3.2)	(3.3)	(3.3)	(3.3)	
	(3.4)			(3.5)			

VARIANCE - COVARIANCE MATRIX OF ERRORS AT INJECTION

	NODE	INC	PERIGEE	A	ECC	EPOCH	
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	(3.6)	____	____	*
*	____	____	____	____	____	____	*
*	____	____	____	____	____	____	*
	*	*	*	*	*	*	

ERRORS IN ORBITAL ELEMENTS -

R A ASC NODE = (3.7) INCLINATION = (3.9) ARG OF PERIGEE = (3.11) .

SEMI-MAJOR A = (3.8) ECCENTRICITY = (3.10) EPOCH = (3.12) .

PREDICTED VARIANCE COVARIANCE MATRIX

PREDICTED ERRORS AT T = (3.13) HRS, (3.13) MIN, (3.13) SEC

	X1	X2	X3	X1.	X2.	X3.	
ERRORS FROM OBSERVATION							
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	(3.14)	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
	*	*	*	*	*	*	
	(3.15)	(3.15)	(3.15)	(3.16)	(3.16)	(3.16)	ERROR
	(3.17)			(3.18)			R AND V

(3.1) Variance—covariance matrix of errors in position and velocity at injection. This matrix is printed only if injection errors were input (columns 4-6 of input card 2 were + 01 or + 02). This matrix is diagonal if injection errors in position and velocity were input with no correlation assumed (columns 7-9 of input card 2 were + 00). If injection errors in height, velocity, flight path angle, azimuth, right ascension, and declination were given (columns 7-9 of input card 2 were + 02 or + 03), then these errors are first transformed into errors in position and velocity at injection before the variance covariance matrix is printed. Position components are given in kilometers and velocity components in kilometers/second.

(3.2) Errors in the inertial position components $(\delta X_1, \delta X_2, \delta X_3)$ at injection in meters. If the injection errors in position and velocity are input, these three quantities will coincide with the first three quantities given on input card 4A.

(3.3) Errors in the inertial velocity components $(\delta \dot{X}_1, \delta \dot{X}_2, \delta \dot{X}_3)$ at injection in meters/second. If the injection errors in position and velocity are input, these three quantities will coincide with the last three quantities given on input card 4A.

(3.4) Error in inertial position $\left(\delta X_1{}^2 + \delta X_2{}^2 + \delta X_3{}^2\right)^{1/2}$ at injection in meters.

(3.5) Error in inertial velocity $\left(\delta \dot{X}_1{}^2 + \delta \dot{X}_2{}^2 + \delta \dot{X}_3{}^2\right)^{1/2}$ at injection in meters/second.

(3.6) Variance-covariance matrix of errors in the orbital elements at injection. The semi-major axis is given in kilometers, the epoch in seconds, and the angles in radians.

(3.7) Error in the right ascension of the ascending node at injection in radians.

(3.8) Error in the semi-major axis at injection in meters.

(3.9) Error in the inclination of the orbit at injection in radians.

(3.10) Error in the eccentricity of the orbit at injection.

(3.11) Error in the argument of perigee at injection in radians.

(3.12) Error in the time of epoch in seconds.

(3.13) Time at which to predict the injection errors in position and velocity (given in hours, minutes, and seconds from epoch time). If columns 4-6 of input card 2 are + 02, the injection errors are predicted to the time given on input card 4G.

(3.14) Variance-covariance matrix of errors in position and velocity at the given time based solely on the errors at injection. Position components are given in kilometers and velocity components in kilometers/second.

(3.15) Errors in the inertial position components $(\delta X_1, \delta X_2, \delta X_3)$ at the given time based solely on the errors at injection. Position errors are given in meters.

(3.16) Errors in the inertial velocity components $(\delta \dot{X}_1, \delta \dot{X}_2, \delta \dot{X}_3)$ at the given time based solely on the errors at injection. Velocity errors are given in meters/second.

(3.17) Total error in inertial position $\left(\delta X_1{}^2 + \delta X_2{}^2 + \delta X_3{}^2\right)^{1/2}$ at the given time based solely on the errors at injection - in meters.

(3.18) Total error in inertial velocity $\left(\delta\dot{X}_1^{\,2} + \delta\dot{X}_2^{\,2} + \delta\dot{X}_3^{\,2}\right)^{1/2}$ at the given time based solely on the errors at injection - in meters/second.

The ellipsoid of errors for position and velocity is given for the predicted variance covariance matrix on the following page. The format is the same as for the ellipsoid of errors for the variance covariance matrix based upon tracking information, which is described in a later section.

4. TRACKING STATION INFORMATION

BEGINNING OF CASE ___(4.1)___

****

VELOCITY OF LIGHT ERROR FACTOR = ___(4.2)___

STATION MAKES OBSERVATIONS WHEN LOCAL ELEVATION ANGLE IS BETWEEN (4.3) AND (4.4) DEGREES.

TRACKING STATIONS USED IN THIS CASE

NUMBER	NAME	LOCATION	ERRORS OBSERVATIONAL	ERRORS POSITIONAL
(4.5)	(4.6)	LATITUDE = (4.7) DEG	RANGE = (4.10) MET	DS1 = (4.16) MET
		LONGITUDE = (4.8) DEG	RANGE RATE = (4.11) MET/SEC	DS2 = (4.17) MET
		HEIGHT = (4.9) MET	AZIMUTH = (4.12a) RAD	DS3 = (4.18) MET
			DIR COS L = (4.12b) RAD	
			ELEVATION = (4.13a) RAD	
			DIR COS M = (4.13b) RAD	
			AZIMUTH RATE = (4.14) RAD/SEC	
			ELEVATION RATE = (4.15) RAD/SEC	

UNITS OPERATING AT THIS STATION –	RANGE RATE	(4.19)	SEC/OBS
	RADAR	(4.19)	SEC/OBS
	RANGE	(4.19)	SEC/OBS
	ANGLE	(4.19)	SEC/OBS

(4.1) Number of the case presently being started.

(4.2) Uncertainty factor in the velocity of light—either the built-in value of 1.0×10^{-6} or the value from input card 11F (or 12K).

(4.3) Visibility bound on the horizon in degrees—either the built-in value of 5° or the value from input card 11D (or 12 I).

(4.4) Visibility bound on the zenith in degrees—either the built-in value of 90° or the value from input card 11D (or 12 I).

(4.5) Number of a tracking station being used on the current case. The output for all the stations used on the case is given—the station numbers were given on input card 11 (and 11A) or input card 12F.

(4.6) Name of the tracking station corresponding to the station number. The names for the tracking stations were given on input card 6.

(4.7) Geodetic latitude of the tracking station in degrees—from input card 6.

(4.8) Geodetic longitude of the tracking station in degrees—from input card 6.

(4.9) Height of the tracking station above the geoid in meters—from input card 6.

(4.10) Standard deviation of the error associated with the range measurement in meters—from input card 7 (or input card 12L).

(4.11) Standard deviation of the error associated with the range rate measurement in meters/sec—from input card 7 (or input card 12L).

(4.12a-b) Standard deviation of the error associated with the measurement of the azimuthal angle (or direction cosine L) in radians—from input card 7 (or input card 12L).

(4.13a-b) Standard deviation of the error associated with the measurement of the elevation angle (or direction cosine M) in radians—from input card 7 (or input card 12L).

(4.14) Standard deviation of the error associated with the measurement of azimuth rate in radians/second—from input card 7A. This is printed only if the option to measure azimuth and elevation rates is specified.

(4.15) Standard deviation of the error associated with the measurement of elevation rate in radians/second—from input card 7A. This is printed only if the option to measure azimuth and elevation rates is specified.

(4.16) Standard deviation of the error in the S_1 component of station location in meters—from input card 7.

(4.17) Standard deviation of the error in the s_2 component of station location in meters—from input card 7.

(4.18) Standard deviation of the error in the s_3 component of station location in meters—from input card 7.

(4.19) Type of tracking station and the sampling rate for the given station. The standard deviations of the errors (4.10), (4.11), (4.12), or (4.13) are set at 0 if that particular measurement is not to be made. The type of station and the sampling rate are given on input card 8 (or input card 12M).

5. INTERVALS OF OBSERVATION

(5.1)	Start pass (5.6) over station (5.7) , (5.8)
(5.2)	* * * *all stations can now see.
(5.3)	end pass (5.6) over station (5.7) , (5.8)
(5.4)	* * * *no station can now see.
(5.5)	* * * *not all stations can now see.

(5.1) Time (hours, minutes, seconds) at which a pass starts (from epoch time)

(5.2) Time (hours, minutes, seconds) when all stations start to observe simultaneously.

(5.3) Time (hours, minutes, seconds) at which a pass ends.

(5.4) Time (hours, minutes, seconds) when no station can observe.

(5.5) Time (hours, minutes, seconds) when the stations no longer can observe simultaneously.

(5.6) Number of the pass over the station.

(5.7) Number of the station.

(5.8) Name of the station.

6. VARIANCE-COVARIANCE MATRICES DUE TO TRACKING

CUMULATED RESULTS
END OF PASS WRITE
TIMEWISE WRITE
$\left.\right\}$ (6.1)

ERRORS BASED ON OBSERVATIONS MADE BETWEEN

(6.2) HRS (6.2) MIN (6.2) SEC AND (6.3) HRS (6.3) MIN (6.3) SEC

FROM EPOCH

NUMBER OF OBSERVATION MADE IN THIS INTERVAL

POSITION (6.4) VELOCITY (6.5)

INJECTION ERRORS INCLUDED (6.6)

VARIANCE-COVARIANCE MATRIX REFERRED TO THE LAST OBSERVATION

	X1	X2	X3	X1.	X2.	X3.	
ERRORS FROM OBSERVATION							
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	(6.7)	______	______	*
*	______	______	______	______	______	______	*
*	______	______	______	______	______	______	*
	*	*	*	*	*	*	
	(6.8)	(6.8)	(6.8)	(6.9)	(6.9)	(6.9)	ERROR R AND V
	(6.10)			(6.11)			

VARIANCE-COVARIANCE OF ORBITAL ELEMENTS

	NODE	INC	PERIGEE	A	ECC	EPOCH	
ERRORS FROM OBSERVATION							
*							*
*							*
*							*
*				(6.12)			*
*							*
*							*
	*	*	*	*	*	*	

ERRORS IN ORBITAL ELEMENTS -

R A ASC NODE = (6.13) INCLINATION = (6.15) ARG OF PERIGEE = (6.17)

SEMI-MAJOR A = (6.14) ECCENTRICITY = (6.16) EPOCH = (6.18)

PREDICTED VARIANCE-COVARIANCE MATRIX

PREDICTED ERROR AT T = (6.19) HRS, (6.19) MIN, (6.19) SEC

	X1	X2	X3	X1.	X2.	X3.	
ERRORS FROM OBSERVATION							
*							*
*							*
*							*
*				(6.20)			*
*							*
*							*
	*	*	*	*	*	*	
	(6.21)	(6.21)	(6.21)	(6.22)	(6.22)	(6.22)	ERROR
	(6.23)			(6.24)			R AND V

	R	V	GAMMA	ALPHA	CHI	DELTA	
*	___	___	______	______	_____	______	*
*	___	___	______	______	_____	______	*
*	___	___	______	______	_____	______	*
*	___	___	______	(6.25)	_____	______	*
*	___	___	______	______	_____	______	*
*	___	___	______	______	_____	______	*
	*	*	*	*	*	*	

ERRORS IN SPHERICAL COORDINATES -

DISTANCE = (6.26) VELOCITY = (6.27) FL PATH ANGLE = (6.28)
AZIMUTH = (6.29) RT ASCENSION = (6.30) DECLINATION = (6.31)

(6.1) Type of printout to follow. A timewise write is given when option "F" or "G" is specified on input card 9 (or input card 12). A passwise write is given when option "A" or "B" is specified on input card 9 (or input card 12).

(6.2) Starting time for the observational period. This is the same as the time given on input card 9 (or input card 12) for cumulated results.

(6.3) Ending time for the current observational period (from epoch time)

(6.4) Number of times that range and/or angle measurements were taken.

(6.5) Number of times that range rate measurements were taken.

(6.6) Notifies the user that the option for injection errors (columns 4-6 of input card 2) is still being retained.

(6.7) Variance-covariance matrix of the errors in position and velocity at the time of the last observation based upon tracking system errors. This is a 6 x 6 matrix containing a 3 x 3 variance-covariance submatrix due to position in the upper left and a 3 x 3 variance-covariance submatrix due to velocity in the lower right. Position components are given in kilometers and velocity components in kilometers/second.

(6.8) Square root of the variances in the inertial position components $(\delta X_1, \delta X_2, \delta X_3)$ in meters. This is not printed if the variance-covariance matrix is improper (negative variances).

(6.9) Square root of the variances in the inertial velocity components $(\delta \dot{X}_1, \delta \dot{X}_2, \delta \dot{X}_3)$ in meters/second. This is not printed if the variance-covariance matrix is improper.

(6.10) Square root of the variance of the range error $(\delta X_1{}^2 + \delta X_2{}^2 + \delta X_3{}^2)^{1/2}$ in meters. This is not printed if the variance-covariance matrix is improper.

(6.11) Square root of the variance of the velocity error $(\delta \dot{X}_1{}^2 + \delta \dot{X}_2{}^2 + \delta \dot{X}_3{}^2)^{1/2}$ in meters/second. This is not printed if the variance-covariance matrix is improper.

(6.12) Variance-covariance matrix of the errors in the orbital elements at the time of the last observation based upon tracking system errors. The semi-major axis is given in kilometers, the epoch in seconds, and the angles in radians.

(6.13) Square root of the variance of the right ascension of the ascending node at the time of the last observation in radians.

(6.14) Square root of the variance of the semi-major axis at the time of the last observation in meters.

(6.15) Square root of the variance of the inclination of the orbit at the time of the last observation in radians.

(6.16) Square root of the variance of the eccentricity of the orbit at the time of the last observation.

(6.17) Square root of the variance of the argument of perigee at the time of the last observation in radians.

(6.18) Square root of the variance of the time of epoch at the time of the last observation in seconds.

(6.19) Time from epoch at which to predict the variance-covariance matrix based upon tracking system errors. If option "X" is specified on input card 9 (or input card 12), the errors in position and velocity are predicted to the time given on input card 11E (or input card 12J).

(6.20) Variance-covariance matrix of errors in position and velocity at the prediction time based upon tracking errors. Position components are given in kilometers and velocity components in kilometers/second.

(6.21) Square root of the variances in the inertial position components $(\delta X_1, \delta X_2, \delta X_3)$ at the prediction time based upon tracking errors, in meters.

(6.22) Square root of the variances in the inertial velocity components $\left(\delta\dot{X}_1, \delta\dot{X}_2, \delta\dot{X}_3\right)$ at the prediction time based upon tracking errors, in meters/second.

(6.23) Square root of the variance of the range error $\left(\delta X_1{}^2 + \delta X_2{}^2 + \delta X_3{}^2\right)^{1/2}$ in meters at the prediction time based upon tracking errors.

(6.24) Square root of the variance of the velocity error $\left(\delta\dot{X}_1{}^2 + \delta\dot{X}_2{}^2 + \delta\dot{X}_3{}^2\right)^{1/2}$ in meters/second at the prediction time based upon tracking errors.

(6.25) Variance-covariance matrix of errors in height, velocity, flight path angle, azimuth, right ascension, and declination. If option "M" is specified on input card 9 (or input card 12), this variance-covariance matrix is printed whenever any variance-covariance matrix of the errors in position and velocity is printed. The height is given in kilometers, the velocity in kilometers/second, and the angles in radians.

(6.26) Square root of the variance of height in meters.

(6.27) Square root of the variance of velocity in meters/second.

(6.28) Square root of the variance of flight path angle in radians.

(6.29) Square root of the variance of azimuth in radians.

(6.30) Square root of the variance of right ascension in radians.

(6.31) Square root of the variance of declination in radians.

7. ELLIPSOID OF ERRORS

ELLIPSOID OF ERRORS FACTOR, B**2 = (7.1)

FOR VARIANCE-COVARIANCE MATRIX REFERRED TO LAST OBSERVATION

FOR PREDICTED VARIANCE-COVARIANCE MATRIX (7.2)

ELLIPSOID OF ERRORS FOR POSITION

EIGENVALUES	L1 =	(7.3)	L2 =	(7.3)	L3 =	(7.3)
SEMI-MAJOR AXES	A =	(7.4)	B =	(7.4)	C =	(7.4)
EIGENVECTORS		(7.5a)		(7.5b)		(7.5c)
		(7.5a)		(7.5b)		(7.5c)
		(7.5a)		(7.5b)		(7.5c)

ELLIPSOID OF ERRORS FOR VELOCITY

EIGENVALUES	L1 =	(7.6)	L2 =	(7.6)	L3 =	(7.6)
SEMI-MAJOR AXES	A =	(7.7)	B =	(7.7)	C =	(7.7)
EIGENVECTORS		(7.8a)		(7.8b)		(7.8c)
		(7.8a)		(7.8b)		(7.8c)
		(7.8a)		(7.8b)		(7.8c)

****

NEXT CASE IS CONTINUATION OF THIS ONE (7.9)

(7.1) Scaling coefficient for the ellipsoid of errors—either the built-in value of 2.795 or the value from input card 11G (or input card 12L). See figure 1 for the corresponding probability.

(7.2) Variance-covariance matrix of the errors in position and velocity for which the ellipsoids of errors are given.

(7.3) The eigenvalues $(\lambda_1, \lambda_2, \lambda_3)$ of the 3 x 3 submatrix in the upper left due to position. The units for the eigenvalues are $1/km^2$.

(7.4) The semi-major axes $\beta/(\lambda_1)^{1/2}$, $\beta/(\lambda_2)^{1/2}$, $\beta/(\lambda_3)^{1/2}$ of the ellipsoid for position errors in meters.

(7.5a-c) The eigenvectors of the 3 x 3 submatrix in the upper left due to position. These eigenvectors give the orientation of axes of the error ellipsoid in terms of the inertial coordinate system.

(7.6) The eigenvalues $(\lambda_4, \lambda_5, \lambda_6)$ of the 3 x 3 submatrix in the lower right due to velocity. The units for the eigenvalues are sec^2/km^2.

(7.7) The semi-major axes $\beta/(\lambda_4)^{1/2}$, $\beta/(\lambda_5)^{1/2}$, $\beta/(\lambda_6)^{1/2}$ of the ellipsoid for velocity errors in meters/second.

(7.8a-c) The eigenvectors of the 3 x 3 submatrix in the lower right due to velocity. These eigenvectors give the orientation of axes of the error ellipsoid in terms of the inertial coordinate system.

(7.9) Notifies the user that option "K" (to continue with the previous case) has been specified. The next cumulated results contain the information processed on this case as well as the next one. Note however that the number of observations is given only for the next time interval to be given.

B. PROGRAM OUTPUT ON THE SUPPLEMENTARY TAPE

The first two pages of the orbit information are also printed on the supplementary tape. In addition, if option "P" is specified for a case on input card 11B (or input card 12G), then the tracking station information and the viewing intervals are printed on the supplementary tape. The following local lines will then be printed at the specified time points.

	RADIUS KM	VELOCITY M/S	STATION	RANGE KM	AZIMUTH DEG
(1)	(2)	(3)	(4)	(5)	(6)

ELEVATION DEG	RNG RATE M/S	AZ RATE D/S	EL RATE D/S	ECC ANOM DEG
(7)	(8)	(9)	(10)	(11)

(1) Time in hours, minutes, and seconds from epoch to which the information applies.

(2) Distance from the center of the earth to the vehicle in kilometers.

(3) Velocity of the vehicle in meters/second.

(4) Station number to which the information applies.

(5) Distance (slant range) from the station to the vehicle in kilometers.

(6) Azimuth of the vehicle with respect to the station in degrees.

(7) Elevation of the vehicle with respect to the station in degrees.

(8) Range rate of the vehicle in meters/second with respect to the station.

(9) Azimuth rate of the vehicle in degrees/second with respect to the station.

(10) Elevation rate of the vehicle in degrees/second with respect to the station.

(11) Eccentric anomaly along the elliptic orbit in degrees.

This program may be used to furnish station predictions only. For this purpose, the sampling rates are made larger than the observational interval so that tracking will not contribute to the variance-covariance matrices. Option "P" is specified so that local lines (or station predictions) will be computed and printed on the supplementary tape. The quantity Δt would determine how often station predictions were computed.

C. SAMPLE OUTPUT ON THE MAIN TAPE

The 6 pages of sample output will be shown for the sample input with no options; the data for this run was given in the input sections. In addition, the pages containing injection error information and the ellipsoid of errors for the predicted injection error matrix will be merged and 2 pages of the second case for the sample output with options will be given to give a variety of output formats.

D. SAMPLE OUTPUT ON THE SUPPLEMENTARY TAPE

The 4 pages of sample output on the supplementary tape will be given for the case of sample output with options; the data for this run was given in the input section.

```
TRACKING SYSTEM ERROR ANALYSIS

ERROR ANALYSIS - PARKING ORBIT - LAUNCH AZIMUTH 90 , HEIGHT 200 KM.

10.0E-09           TOLERANCE REQUIRED FOR XKEPZ FUNCTION

6378.165           EQUATORIAL RADIUS OF EARTH IN KM
 298.3             INVERSE OF FLATTENING
3.98603198E 05     GM (KM. CUBED/SECONDS SQUARED)

 8/ 5/1961         EPOCH DATE OF PARAMETERS
 0  5  0.600       EPOCH TIME OF PARAMETERS-UT2

  1                INPUT OPTION NUMBER
                   INPUT PARAMETERS ARE---

ORBITAL ELEMENTS - OSCULATING
REQUIRED UNITS - ALL ANGLES IN DEGREES.SEMI-MAJOR AXIS IN KILOMETERS

   6625.6000       SEMI-MAJOR AXIS-KILOMETERS
      0.00712000   ECCENTRICITY
     28.500000     INCLINATION     -DEGREES
    143.983999     R.A. ASC. NODE  -DEGREES
     97.000000     ARG. OF PERIGEE-DEGREES
      0.           MEAN ANOMALY    -DEGREES
```

```
ERROR ANALYSIS - PARKING ORBIT - LAUNCH AZIMUTH 90 , HEIGHT 200 KM.

QUANTITIES COMPUTED FROM INPUT

 8/ 5/1961          EPOCH DATE OF PARAMETERS
 0  5  0.600        EPOCH TIME OF PARAMETERS-UT2

    POSITION AND VELOCITY VECTORS - GEOCENTRIC EQUATORIAL INERTIAL

  -2725.62662       X1  - KILOMETERS
  -5112.72467       X2  - KILOMETERS
   3115.55615       X3  - KILOMETERS

      6.76344121    VX1 - KM/SEC
     -3.88244987    VX2 - KM/SEC
     -0.45426302    VX3 - KM/SEC

   6578.42566       R   - KILOMETERS
      7.81178015    V   - KM/SEC

                                ORBITAL ELEMENTS

OSCULATING ELEMENTS

   6625.6000                                    SEMI-MAJOR AXIS - KILOMETERS
      0.00712000                                ECCENTRICITY
     28.500000                                  INCLINATION     - DEGREES
    143.983999                                  R.A. ASC. NODE  - DEGREES
     97.000000                                  ARG. OF PERIGEE - DEGREES
      0.                                        MEAN ANOMALY    - DEGREES

      1.490887      PERIOD          -HOURS
     89.4532                        -MINUTES
    241.466955      MEAN MOTION     -DEGREES/HOUR


    314.562332       SIDEREAL TIME AT EPOCH - DEGREES


   6578.4257                    PERICENTER - KILOMETERS
   6672.7742                    APOCENTER  - KILOMETERS
```

VARIANCE-COVARIANCE MATRIX OF ERRORS AT INJECTION

	X1	X2	X3	X1.	X2.	X3.	
*	3.9999999E-02	0.	0.	0.	0.	0.	*
*	0.	3.9999999E-02	0.	0.	0.	0.	*
*	0.	0.	3.9999999E-02	0.	0.	0.	*
*	0.	0.	0.	2.4999999E-03	0.	0.	*
*	0.	0.	0.	0.	2.4999999E-03	0.	*
*	0.	0.	0.	0.	0.	2.4999999E-03	*
	*	*	*	*	*	*	
	1.9999999E 02	1.9999999E 02	1.9999999E 02	4.9999998E 01	4.9999998E 01	4.9999998E 01	ERROR
	3.4641015E 02			8.6602536E 01			R AND V

VARIANCE-COVARIANCE MATRIX OF ERRORS AT INJECTION

	NODE	INC	PERIGEE	A	ECC	EPOCH	
*	1.8152988E-04	5.8426796E-06	-1.5977412E-04	-6.2104087E-10	-1.3512592E-14	-1.2512267E-09	*
*	5.8426796E-06	1.8897972E-07	-5.1424536E-06	-1.9987995E-11	-4.3490549E-16	-4.0270308E-11	*
*	-1.5977412E-04	-5.1424537E-06	5.3432722E-02	1.9776974E 01	2.4457957E-04	4.0054496E 01	*
*	-1.1950995E-09	-3.8464516E-11	1.9776974E 01	7.4016561E 03	1.4176404E-01	1.4933949E 04	*
*	-2.0150583E-14	-6.4855450E-16	2.4457957E-04	1.4176404E-01	4.2886075E-05	2.4076295E-01	*
*	-2.4143938E-09	-7.7707742E-11	4.0054496E 01	1.4933949E 04	2.4076295E-01	3.0182702E 04	*
	*	*	*	*	*	*	

ERRORS IN ORBITAL ELEMENTS -

R A ASC NODE= 1.35E-02 RAD   INCLINATION = 4.35E-04 RAD   ARG OF PERIGEE= 2.31E-01 RAD

SEMI MAJOR A= 8.60E 04 METERS   ECCENTRICITY= 6.55E-03 -   EPOCH = 1.74E 02 SEC

PREDICTED VARIANCE-COVARIANCE MATRIX

PREDICTED ERRORS AT T= 1 HRS. 30 MIN. -C. SEC

ERRORS FROM OBSERVATION

	X1	X2	X3	X1.	X2.	X3.	
*	5.1571927E 05	-2.7309214E 05	2.3301922E 04	2.3023921E 02	5.6473840E 02	-3.2879098E 02	*
*	-2.7309214E 05	1.4461573E 05	-1.2339282E 04	-1.2187447E 02	-2.9897070E 02	1.7410785E 02	*
*	2.3301922E 04	-1.2339282E 04	1.0555936E 03	1.0397930E 01	2.5517646E 01	-1.4774086E 01	*
*	2.3023921E 02	-1.2187447E 02	1.0397930E 01	1.0339754E-01	2.5316331E-01	-1.4689956E-01	*
*	5.6473840E 02	-2.9897070E 02	2.5517646E 01	2.5316331E-01	6.2022659E-01	-3.5994791E-01	*
*	-3.2879098E 02	1.7410785E 02	-1.4774086E 01	-1.4689956E-01	-3.5994791E-01	2.1210225E-01	*
	*	*	*	*	*	*	
	7.1813596E 05	3.8028374E 05	3.2489900E 04	3.2155487E 02	7.8754465E 02	4.6054559E 02	ERROR
	8.1325923E 05			9.6732949E 02			R AND V

FOR PREDICTED VARIANCE COVARIANCE MATRIX

ELLIPSOID OF ERRORS FOR POSITION

EIGENVALUES	L1= 1.512E-06	L2= 3.662E-01	L3= 3.664E-01
	L4=		
SEMI-MAJOR AXES	A= 4.864E 05	B= 9.884E 02	C= 9.882E 02
	D=		
EIGENVECTORS	8.830E-01	-4.676E-01	3.990E-02
	4.680E-01	8.837E-01	0.
	-3.526E-02	1.867E-02	9.992E-01

ELLIPSOID OF ERRORS FOR VELOCITY

EIGENVALUES	L1= 1.905E 04	L2= 1.072E 00	L3= 4.006E 02
	L4=		
SEMI-MAJOR AXES	A= 4.334E 00	B= 5.778E 02	C= 2.989E 01
	D=		
EIGENVECTORS	9.236E-01	-3.832E-01	-1.057E-02
	3.327E-01	8.149E-01	-4.746E-01
	1.905E-01	4.348E-01	8.802E-01

BEGINNING OF CASE 1

* *

VELOCITY OF LIGHT ERROR FACTOR = 1.0000E-06

STATION MAKES OBSERVATIONS WHEN LOCAL ELEVATION ANGLE IS BETWEEN 5.00 AND 90.00 DEGREES.

TRACKING STATIONS USED IN THIS CASE

NUMBER	NAME	LOCATION	ERRORS OBSERVATIONAL		ERRORS POSITIONAL	
1	CARNARVON	LATITUDE = -24.86667 DEG	RANGE = 1.500000E 01 MET	DS1	= 0.	MET
		LONGITUDE = 113.63333 DEG	RANGE RATE=10.000000E-02 MET/SEC	DS2	= 0.	MET
		HEIGHT = 0. MET	AZIMUTH = 2.000000E-04 RAD	DS3	= 0.	MET
			ELEVATION = 2.000000E-04 RAD			
		UNITS OPERATING AT THIS STATION -	RANGE RATE 1.00 SEC/OBS			
			RADAR 1.00 SEC/OBS			

```
0 45 -0.          ****NO STATION CAN NOW SEE.
0 45 34.000       START PASS   1 OVER STATION  1.  CARNARVON
0 45 34.000       ****ALL STATIONS CAN NOW SEE.
0 52 22.000       END PASS   1 OVER STATION  1.  CARNARVON
0 52 22.000       ****NO STATION CAN NOW SEE.
```

CUMULATED RESULTS

ERRORS BASED ON OBSERVATIONS MADE BETWEEN 0 HRS 45 MIN -0. SEC AND 0 HRS 53 MIN 59.00 SEC FROM EPOCH

NUMBER OF OBSERVATIONS MADE IN THIS INTERVAL POSITION 408 VE_OCITY 408

VARIANCE-COVARIANCE MATRIX REFERRED TO THE LAST OBSERVATION

		X1	X2	X3	X1.	X2.	X3.	
ERRORS FROM OBSERVATION								
	*	1.6890287E-05	3.5130851E-05	3.9147936E-05	7.8212271E-08	1.5149130E-07	1.6548505E-07	*
	*	3.5130851E-05	8.2459538E-05	7.3857619E-05	1.4958107E-07	3.4826207E-07	3.0110134E-07	*
	*	3.9147936E-05	7.3857619E-05	1.8038600E-04	2.5550854E-07	2.8671006E-07	8.1268097E-07	*
	*	7.8212271E-08	1.4958107E-07	2.5550854E-07	4.8964531E-10	7.3874125E-10	1.2331343E-09	*
	*	1.5149130E-07	3.4826207E-07	2.8671006E-07	7.3874125E-10	1.7270895E-09	1.3620480E-09	*
	*	1.6548505E-07	3.0110134E-07	8.1268097E-07	1.2331343E-09	1.3620480E-09	3.8916062E-09	*
		*	*	*	*	*	*	
		4.1097794E 00	9.0807234E 00	1.3430786E 01	2.2127930E-02	4.1558266E-02	6.2382740E-02	ERROR
		1.6725305E 01			7.8155876E-02			R AND V

VARIANCE-COVARIANCE MATRIX OF ORBITAL ELEMENTS

		NODE	INC	PERIGEE	A	ECC	EPOCH	
ERRORS FROM OBSERVATION								
	*	3.2669054E-10	-6.8661108E-11	-1.6316739E-09	2.4707755E-08	-1.1612107E-12	-1.1773453E-06	*
	*	-6.8661108E-11	1.4964269E-11	3.6153600E-10	-9.0637431E-09	6.0080916E-13	2.6594292E-07	*
	*	-1.6316739E-09	3.6153600E-10	2.8273152E-07	-7.6811369E-07	-5.0775580E-10	2.4440482E-04	*
	*	2.4707755E-08	-9.0637431E-09	-7.6811368E-07	1.0735949E-04	-1.2997494E-08	-7.1097906E-04	*
	*	-1.1612107E-12	6.0080916E-13	-5.0775580E-10	-1.2997494E-08	2.9377486E-12	-4.3355699E-07	*
	*	-1.1773453E-06	2.6594292E-07	2.4440482E-04	-7.1097906E-04	-4.3355699E-07	2.1148181E-01	*
		*	*	*	*	*	*	

ERRORS IN ORBITAL ELEMENTS -

R A ASC NODE= 1.81E-05 RAD   INCLINATION = 3.87E-06 RAD   ARG OF PERIGEE= 5.32E-04 RAD
SEMI MAJOR A= 1.04E 01 METERS   ECCENTRICITY= 1.71E-06 -   EPOCH = 4.60E-01 SEC

```
ELLIPSOID OF ERRORS FACTOR, B**2=2.7950E 00
                                 FOR VARIANCE-COVARIANCE MATRIX REFERRED TO LAST OBSERVATION

ELLIPSOID OF ERRORS FOR POSITION

    EIGENVALUES        L1=  8.112E 05     L2=  2.160E 04     L3=  4.306E 03
                       L4=
    SEMI-MAJOR AXES        A=  6.641E-01     B=  4.070E 00     C=  9.115E 00
                           D=
    EIGENVECTORS              9.349E-01     -3.497E-01     -6.014E-02
                              2.687E-01      8.084E-01     -5.237E-01
                              2.317E-01      4.735E-01      8.498E-01

ELLIPSOID OF ERRORS FOR VELOCITY

    EIGENVALUES        L1=  4.752E 10     L2=  9.227E 08     L3=  1.999E 08
                       L4=
    SEMI-MAJOR AXES        A=  2.744E-03     B=  1.969E-02     C=  4.231E-02
                           D=
    EIGENVECTORS              9.470E-01     -2.352E-01     -2.189E-01
                              1.082E-01      8.749E-01     -4.720E-01
                              3.026E-01      4.232E-01      8.540E-01

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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                                                    BEGINNING OF CASE   2

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VELOCITY OF LIGHT ERROR FACTOR =  1.0000E-06

STATION MAKES OBSERVATIONS WHEN LOCAL ELEVATION ANGLE IS BETWEEN  5.00 AND 90.00 DEGREES.

                                             TRACKING STATIONS USED IN THIS CASE

NUMBER     NAME                      LOCATION                                              ERRORS
                                                                          OBSERVATIONAL                     POSITIONAL

   1     CARNARVON            LATITUDE  = -24.86667 DEG       RANGE      = 1.500000E 01 MET      DS1     = 0.          MET
                              LONGITUDE = 113.63333 DEG       RANGE RATE= 0.            MET/SEC  DS2     = 0.          MET
                              HEIGHT = 0.             MET     AZIMUTH    = 2.000000E-04 RAD      DS3     = 0.          MET
                                                              ELEVATION = 2.000000E-04 RAD
                              UNITS OPERATING AT THIS STATION -  RADAR         1.00 SEC/OBS

   2     GUAYMAS              LATITUDE  =  28.03333 DEG       RANGE      = 6.000000E 00 MET      DS1     = 0.          MET
                              LONGITUDE =-110.83000 DEG       RANGE RATE= 0.            MET/SEC  DS2     = 0.          MET
                              HEIGHT = 0.             MET     AZIMUTH    = 6.000000E-04 RAD      DS3     = 0.          MET
                                                              ELEVATION = 6.000000E-04 RAD
                              UNITS OPERATING AT THIS STATION -  RADAR         1.00 SEC/OBS
```

END OF PASS WRITE

ERRORS BASED ON OBSERVATIONS MADE BETWEEN 0 HRS 53 MIN 42.00 SEC AND 1 HRS 28 MIN 13.00 SEC FROM EPOCH

NUMBER OF OBSERVATICNS MADE IN THIS INTERVAL POSITION 218

INJECTION ERRORS INCLUDED

VARIANCE-COVARIANCE MATRIX REFERRED TO THE LAST OBSERVATION

ERRORS FROM OBSERVATION

	X1	X2	X3	X1.	X2.	X3.	
*	4.1828654E-04	3.7985582E-04	1.3527226E-04	2.6566444E-06	3.2339193E-06	6.7391400E-07	*
*	3.7985582E-04	3.7362843E-04	3.2521617E-04	2.3320459E-06	3.2162538E-06	2.0083410E-06	*
*	1.3527226E-04	3.2521617E-04	1.5410825E-03	2.2566368E-07	3.0179146E-06	1.0621968E-05	*
*	2.6566444E-06	2.3320459E-06	2.2566368E-07	1.7710779E-08	1.9990271E-08	-1.4739901E-09	*
*	3.2339193E-06	3.2162538E-06	3.0179146E-06	1.9990271E-08	2.7862426E-08	1.8259666E-08	*
*	6.7391400E-07	2.0083410E-06	1.0621968E-05	-1.4739901E-09	1.8259666E-08	7.6718306E-08	*
	*	*	*	*	*	*	
	2.0452054E 01	1.9329470E 01	3.9256623E 01	1.3308185E-01	1.6692042E-01	2.7698069E-01	ERROR
	4.9301111E 01			3.4970202E-01			R AND V

VARIANCE-COVARIANCE MATRIX OF ORBITAL ELEMENTS

ERRORS FROM OBSERVATION

	NODE	INC	PERIGEE	A	ECC	EPOCH	
*	5.3826749E-09	8.5896776E-10	-7.0681541E-09	-1.2932369E-07	2.3787625E-10	-1.3955359E-06	*
*	8.5896776E-10	1.3798828E-10	-1.0637898E-09	-9.2980855E-09	3.1981539E-11	-1.9579374E-07	*
*	-7.0681541E-09	-1.0637898E-09	4.0164106E-08	1.2376259E-07	-4.2086098E-09	2.1063665E-05	*
*	-1.2932369E-07	-9.2980855E-09	1.2376259E-07	3.2943962E-04	8.8113109E-08	-3.2329710E-04	*
*	2.3787625E-10	3.1981539E-11	-4.2086098E-09	8.8113109E-08	5.2851787E-10	-2.5721798E-06	*
*	-1.3955359E-06	-1.9579374E-07	2.1063665E-05	-3.2329710E-04	-2.5721798E-06	1.2674160E-02	*
	*	*	*	*	*	*	

ERRORS IN ORBITAL ELEMENTS -

R A ASC NODE= 7.34E-05 RAD INCLINATION = 1.17E-05 RAD ARG OF PERIGEE= 2.00E-04 RAD

SEMI MAJOR A= 1.82E 01 METERS ECCENTRICITY= 2.30E-05 - EPOCH = 1.13E-01 SEC

```
TRACKING SYSTEM ERROR ANALYSIS

ERROR ANALYSIS - PARKING ORBIT A90 H200 , 2 STATIONS

10.0E-09             TOLERANCE REQUIRED FOR XKEPZ FUNCTION

6378.165             EQUATORIAL RADIUS OF EARTH IN KM
 298.3               INVERSE OF FLATTENING
3.98603198E 05       GM (KM. CUBED/SECONDS SQUARED)

 8/ 5/1961           EPOCH DATE OF PARAMETERS
 0  5  0.600         EPOCH TIME OF PARAMETERS-UT2

  2                  INPUT OPTION NUMBER
                     INPUT PARAMETERS ARE---

GEOCENTRIC EQUATORIAL INERTIAL COORDINATES
REQUIRED UNITS - KILOMETERS AND KILOMETERS/SECOND
  -2725.62662      X1  - KILOMETERS
  -5112.72467      X2  - KILOMETERS
   3115.55612      X3  - KILOMETERS

      6.76344121   VX1 - KM/SEC
     -3.88244984   VX2 - KM/SEC
      0.45426302   VX3 - KM/SEC
```

```
ERROR ANALYSIS - PARKING ORBIT A90 H200 . 2 STATIONS

QUANTITIES COMPUTED FROM INPUT

8/ 5/1961          EPOCH DATE OF PARAMETERS
0  5  0.600        EPOCH TIME OF PARAMETERS-UT2

    POSITION AND VELOCITY VECTORS - GEOCENTRIC EQUATORIAL INERTIAL

 -2725.62662     X1  - KILOMETERS
 -5112.72467     X2  - KILOMETERS
  3115.55612     X3  - KILOMETERS

    6.76344121   VX1 - KM/SEC
   -3.88244984   VX2 - KM/SEC
    0.45426302   VX3 - KM/SEC

  6578.42560     R   - KILOMETERS
    7.81178010   V   - KM/SEC

                        ORBITAL ELEMENTS

OSCULATING ELEMENTS

  6625.5997                                 SEMI-MAJOR AXIS - KILOMETERS
     0.05553778                             ECCENTRICITY
    28.339141                               INCLINATION     - DEGREES
   156.342972                               R.A. ASC. NODE  - DEGREES
     0.317784                               ARG. OF PERIGEE - DEGREES
    79.478554                               MEAN ANOMALY    - DEGREES

     1.490887   PERIOD          -HOURS
    89.4532                     -MINUTES
   241.466967   MEAN MOTION     -DEGREES/HOUR


   314.562332    SIDEREAL TIME AT EPOCH - DEGREES


  6257.6286                 PERICENTER - KILOMETERS
  6993.5707                 APOCENTER  - KILOMETERS
```

```
                                                BEGINNING OF CASE   1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 STATION MAKES OBSERVATIONS WHEN LOCAL ELEVATION ANGLE IS BETWEEN  5.00 AND 90.00 DEGREES.

                                            TRACKING STATIONS USED IN THIS CASE

 NUMBER      NAME                        LOCATION                                             ERRORS
                                                                        OBSERVATIONAL                     POSITIONAL

    1      CARNARVON          LATITUDE  = -24.86667 DEG         RANGE      = 1.500000E 01 MET       DS1     = 0.          MET
                              LONGITUDE = 113.63333 DEG         RANGE RATE=10.000000E-02 MET/SEC  DS2     = 0.          MET
                              HEIGHT = 0.               MET     AZIMUTH    = 2.000000E-04 RAD       DS3     = 0.          MET
                                                                ELEVATION = 2.000000E-04 RAD
                              UNITS OPERATING AT THIS STATION - RANGE RATE      1.00 SEC/OBS
                                                                  RADAR         1.00 SEC/OBS

    2      GUAYMAS            LATITUDE  =  28.03333 DEG         RANGE      = 6.000000E 00 MET       DS1     = 0.          MET
                              LONGITUDE =-110.83000 DEG         RANGE RATE=10.000000E-02 MET/SEC  DS2     = 0.          MET
                              HEIGHT = 0.               MET     AZIMUTH    = 6.000000E-04 RAD       DS3     = 0.          MET
                                                                ELEVATION = 6.000000E-04 RAD
                              UNITS OPERATING AT THIS STATION - RANGE RATE      1.00 SEC/OBS
                                                                  RADAR         1.00 SEC/OBS
```

0 45 -0.   ****NO STATION CAN NOW SEE.

0 49 33.000   START PASS 1 OVER STATION 1. CARNARVON

	RADIUS KM	VELOCITY M/S	STATION	RANGE KM	AZIMUTH DEG	ELEVATION DEG	RNG RATE M/Z	AZ RATE D/S	EL RATE D/S	ECC ANOM DEG
0 49 45.000	6584.	7806	1	1121.	-113.6	5.9	-6906.5	-1.104E-01	7.600E-02	276.533
0 50 -0.	6578.	7813	1	1018.	-115.4	7.1	-6840.3	-1.341E-01	8.473E-02	277.547
0 50 15.000	6571.	7821	1	916.	-117.6	8.5	-6745.4	-1.663E-01	9.598E-02	278.561
0 50 30.000	6565.	7828	1	816.	-120.5	10.0	-6607.4	-2.110E-01	1.106E-01	279.576
0 50 45.000	6558.	7836	1	718.	-124.1	11.8	-6402.3	-2.751E-01	1.296E-01	280.591
0 51 -0.	6552.	7844	1	624.	-128.9	13.9	-6088.6	-3.697E-01	1.533E-01	281.608
0 51 15.000	6546.	7851	1	536.	-135.4	16.4	-5594.2	-5.122E-01	1.797E-01	282.626
0 51 30.000	6539.	7859	1	458.	-144.6	19.3	-4796.1	-7.251E-01	1.977E-01	283.645
0 51 45.000	6533.	7866	1	395.	-157.5	22.1	-3516.9	-1.013E 00	1.738E-01	284.665
0 52 -0.	6527.	7874	1	356.	-174.9	24.0	-1625.0	-1.284E 00	5.621E-02	285.686
0 52 15.000	6520.	7881	1	348.	165.1	23.4	678.1	-1.327E 00	-1.326E-01	286.708
0 52 30.000	6514.	7889	1	375.	146.7	20.4	2806.9	-1.097E 00	-2.565E-01	287.731
0 52 45.000	6508.	7896	1	429.	132.5	16.3	4356.1	-7.979E-01	-2.706E-01	288.755
0 53 -0.	6502.	7904	1	503.	122.4	12.5	5351.2	-5.628E-01	-2.342E-01	289.780
0 53 15.000	6495.	7911	1	588.	115.3	9.3	5972.3	-4.031E-01	-1.916E-01	290.806
0 53 30.000	6489.	7918	1	681.	110.1	6.7	6367.5	-2.974E-01	-1.563E-01	291.833

0 53 42.000   END PASS 1 OVER STATION 1. CARNARVON

0 53 42.000   ****NO STATION CAN NOW SEE.

1 24 35.000   START PASS 1 OVER STATION 2. GUAYMAS

1 24 45.000	6461.	7952	2	541.	-114.4	6.8	-7080.2	-1.919E-01	1.974E-01	63.396
1 25 -0.	6467.	7945	2	436.	-118.0	10.4	-6856.1	-3.017E-01	2.823E-01	64.427
1 25 15.000	6473.	7937	2	336.	-124.0	15.7	-6401.8	-5.313E-01	4.390E-01	65.457
1 25 30.000	6479.	7930	2	247.	-135.6	24.2	-5330.3	-1.099E 00	7.137E-01	66.487
1 25 45.000	6485.	7923	2	185.	-161.5	36.4	-2614.8	-2.538E 00	7.914E-01	67.515
1 26 -0.	6491.	7916	2	179.	152.2	40.4	1955.9	-3.008E 00	-3.797E-01	68.543
1 26 15.000	6498.	7908	2	235.	120.0	30.9	5029.0	-1.379E 00	-6.688E-01	69.569
1 26 30.000	6504.	7901	2	321.	105.8	22.6	6254.4	-6.354E-01	-4.435E-01	70.595
1 26 45.000	6510.	7893	2	419.	98.7	17.2	6753.4	-3.470E-01	-2.883E-01	71.619
1 27 -0.	6516.	7886	2	522.	94.6	13.6	6986.1	-2.149E-01	-2.013E-01	72.643
1 27 15.000	6523.	7878	2	628.	92.0	11.0	7107.2	-1.450E-01	-1.507E-01	73.665
1 27 30.000	6529.	7871	2	735.	90.1	9.0	7174.6	-1.039E-01	-1.192E-01	74.687
1 27 45.000	6535.	7863	2	843.	88.8	7.3	7213.3	-7.790E-02	-9.862E-02	75.708
1 28 -0.	6542.	7856	2	951.	87.7	6.0	7235.3	-6.039E-02	-8.444E-02	76.727

1 28 13.000   END PASS 1 OVER STATION 2. GUAYMAS

1 28 13.000   ****NO STATION CAN NOW SEE.

APPENDIX

The coding for the main program and the subroutines is done in FORTRAN II and FAP. The program requires about 90% of the storage capacity of the 32K IBM 7094 computer.

The main output tape is designated as logical tape 3 (which is equivalent to A3 at the Goddard Space Flight Center). The supplementary output tape is designated as logical tape 5 (which is equivalent to A5 at the Goddard Space Flight Center). A Fortran II systems tape is required. The input data reads from the card reader - thus the binary deck of the program may be stored and saved on a tape.

ACKNOWLEDGMENT

The author wishes to acknowledge the assistance of Mrs. A. Marlow in reviewing the input and output sections of this report in detail.

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3. International Business Machines Corporation, "Reference Manual 709/7090 FORTRAN Programming System", (C28-6054-2).